Current and Future Neutron Scattering Instrumentation

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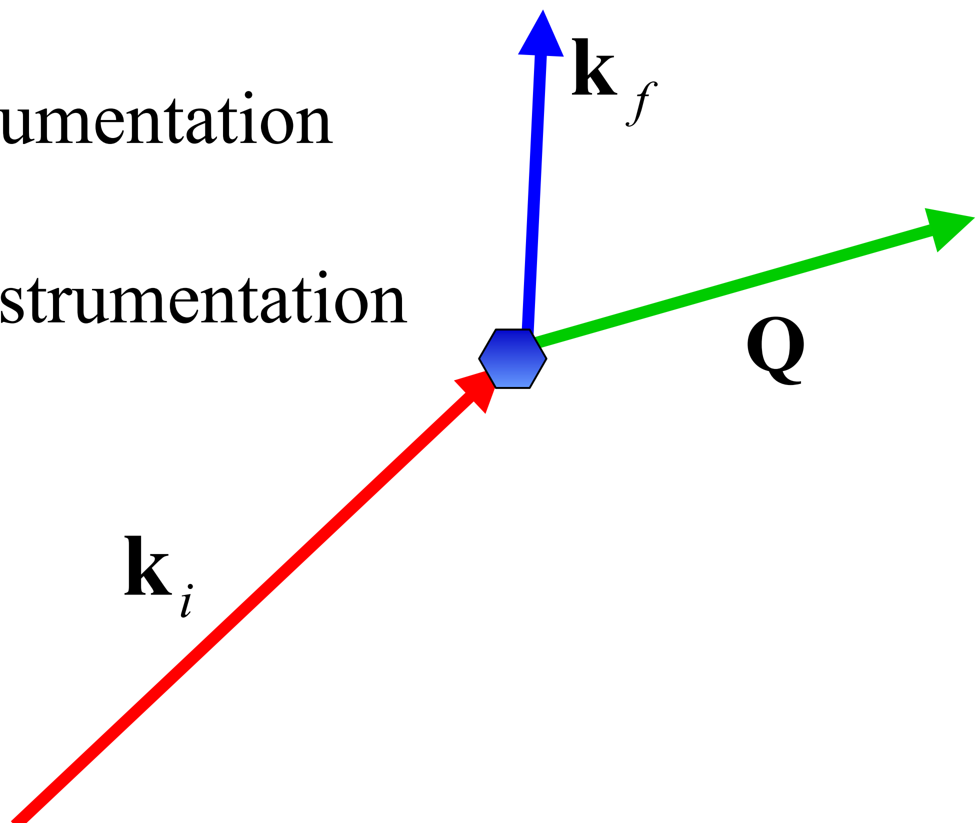
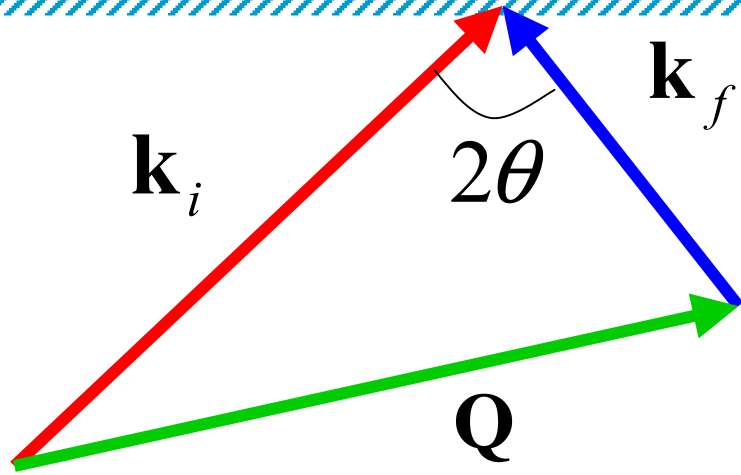
Johns Hopkins University and NIST Center for Neutron Research

- Virtues and Limitations of Neutron Scattering
- New Sources and Instrumentation
- Capabilities of New Instrumentation
- Conclusions



* *supported by NSF DMR-0074571*

Neutron Scattering - in a nutshell



$$\mathbf{Q} = \mathbf{k}_i - \mathbf{k}_f$$

$$\hbar\omega = E_i - E_f$$

Nuclear scattering

$$\mathrm{S}(\mathbf{Q},\omega) = \frac{1}{2\pi\hbar}\int dt\; e^{-i\omega t}\,\frac{1}{N}\left\langle \rho_{\mathbf{Q}}(0)\rho_{-\mathbf{Q}}(t)\right\rangle$$

Magnetic scattering

$$\mathrm{S}^{\alpha\beta}(\mathbf{Q},\omega) = \frac{1}{2\pi\hbar}\int dt\; e^{-i\omega t}\,\frac{1}{N}\sum_{\mathbf{RR'}} e^{i\mathbf{Q}\cdot(\mathbf{R}-\mathbf{R'})} < S^{\alpha}_{\mathbf{R}}(0)\,\mathrm{S}^{\beta}_{\mathbf{R'}}(t) >$$

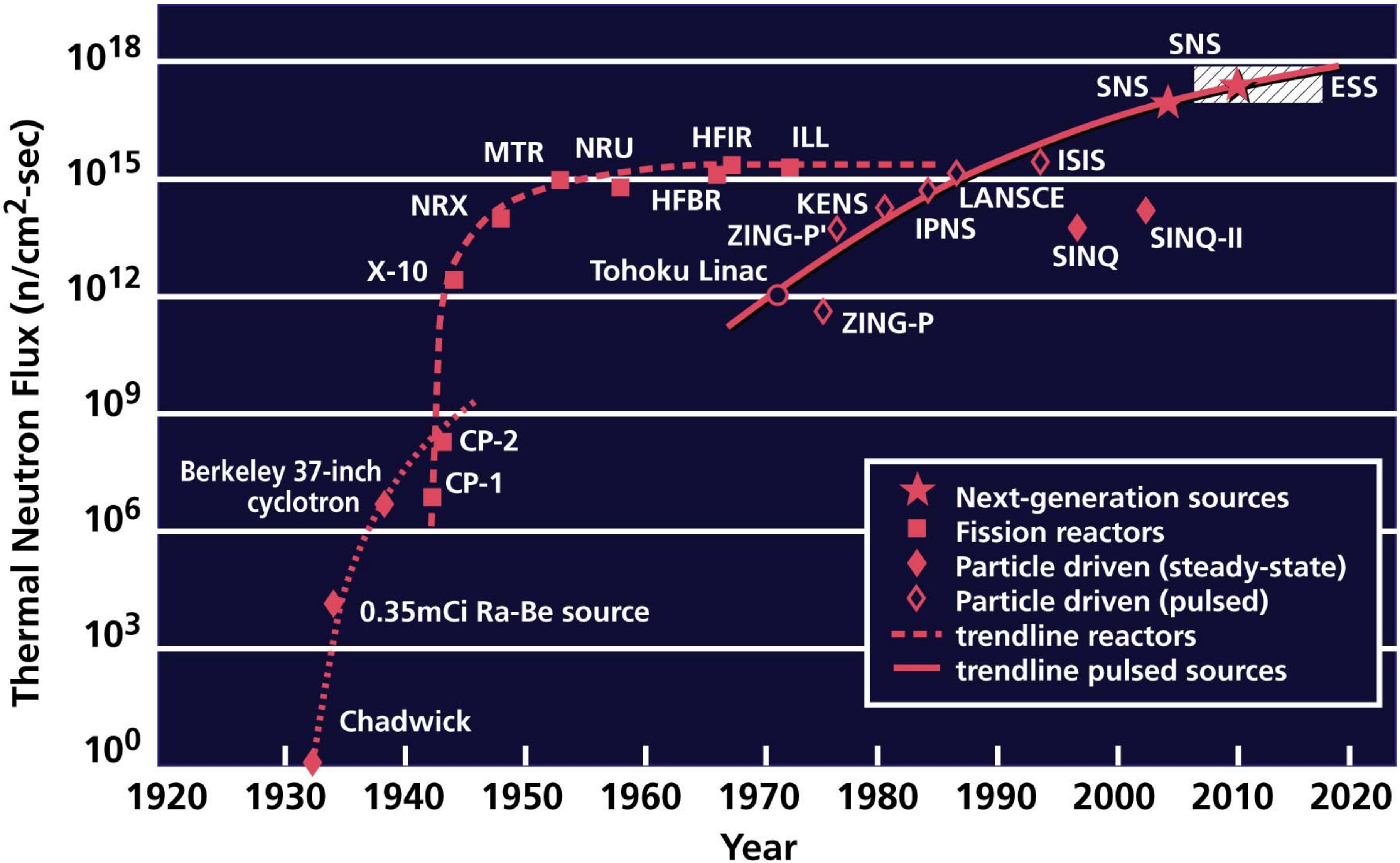
What makes it so hard?

- Neutrons tightly bound in nuclei
  - 190 MeV per free neutron from fission
  - 30 MeV per free neutron from spallation
- $\sigma \propto r_c^2$ a factor Z^2 less than X-ray scattering
- Things we can’t do with current instrumentation
  - dynamics in samples < 1 mm^3
  - dynamics in nano-structured solids
  - Lateral surface structure
  - complex materials with weak signals
  - Signals from impurities at low concentration
  - Spatial and temporal resolution
  - Pressure above 25 GPa

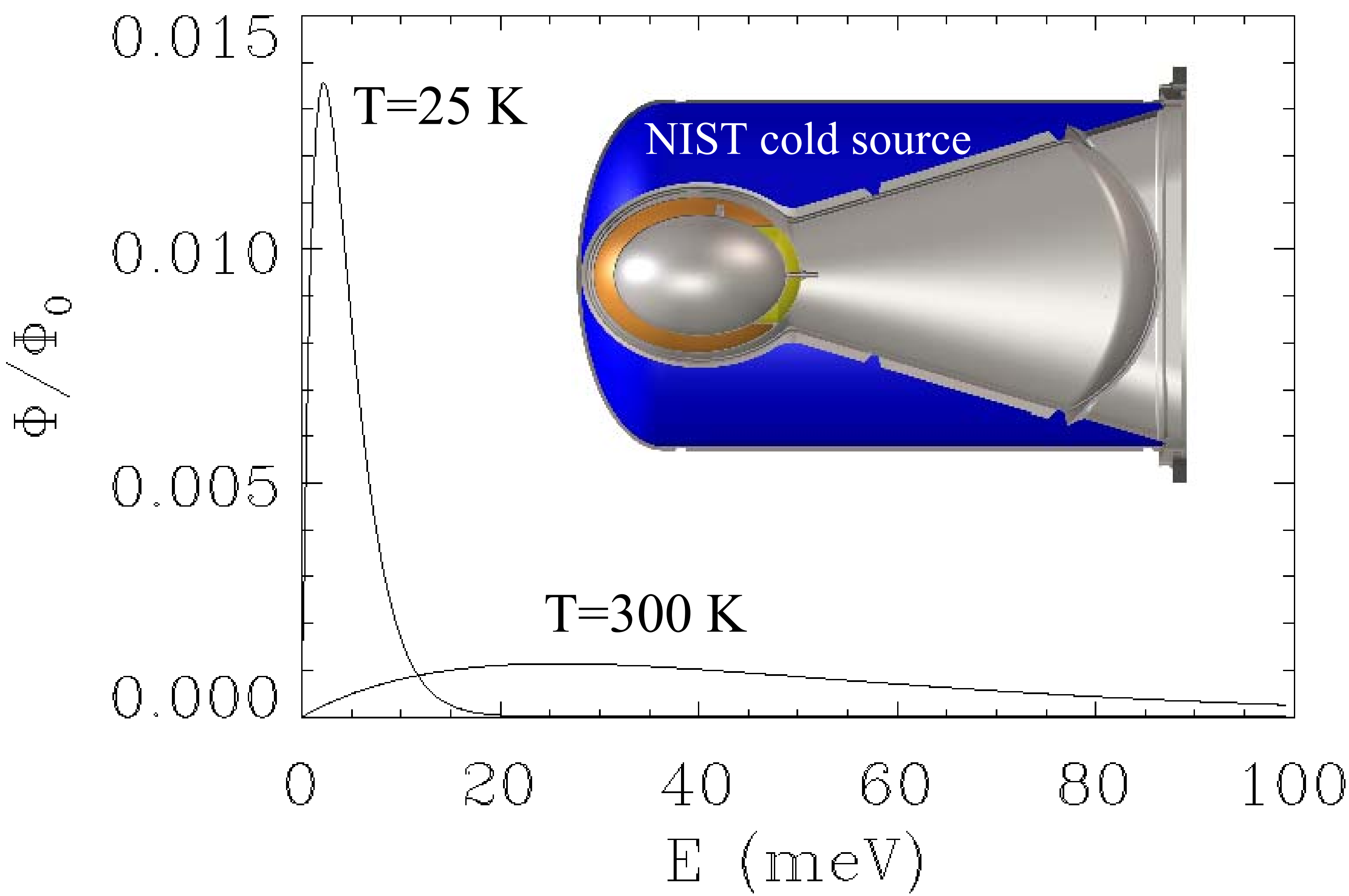
Expanding Applicability of a Powerful Probe

- Increase source brightness
  - Increase spectral brightness by cooling neutrons
  - Increase temporal brightness in pulsed neutron source
- Improve beam delivery system
  - Match solid angle to wave vector resolution requirements
  - Match bandwidth to energy resolution requirements
- Efficiency of detection system
  - Position sensitive detectors
  - Crystal analyzer arrays

Decades of starvation



Brightness from cooling



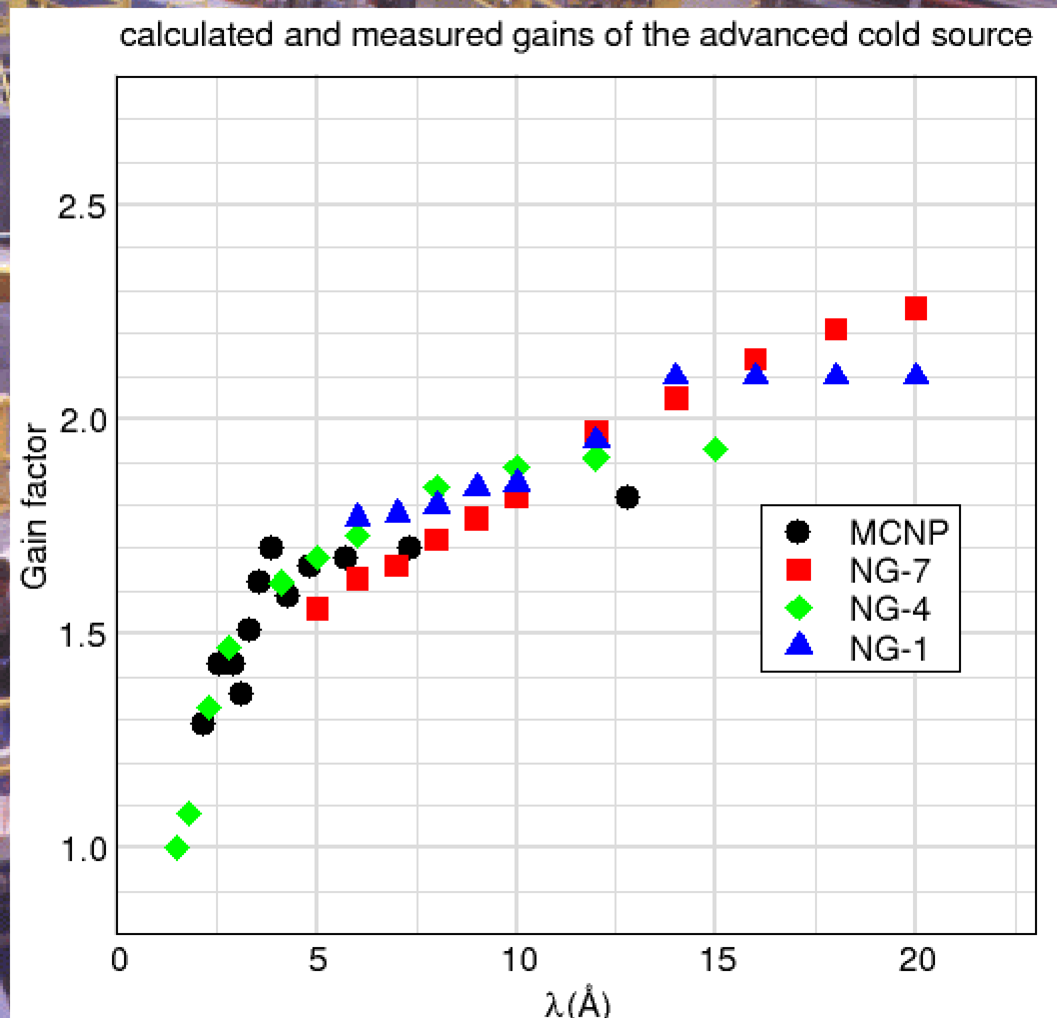
New Instrumentation and Sources

NIST cold source and instrument upgrade	2002-6
HFIR cold source and instrument upgrade	2002-4
LANSCE source and instrument upgrade	2002
US Spallation Neutron Source	2006-8
German high flux research reactor	2004
Australian high flux research reactor	2005
Japanese Spallation Neutron Source	2006
ISIS target Station II	?
SNS 3-5 MW power upgrade	?
SNS long wave length target station	?
European Spallation Neutron Source	?
Chinese Advanced Research reactor	?
New Canadian neutron source	?

NIST Center for Neutron Research

20 MW fission neutron source

With H_2 Cold neutron source



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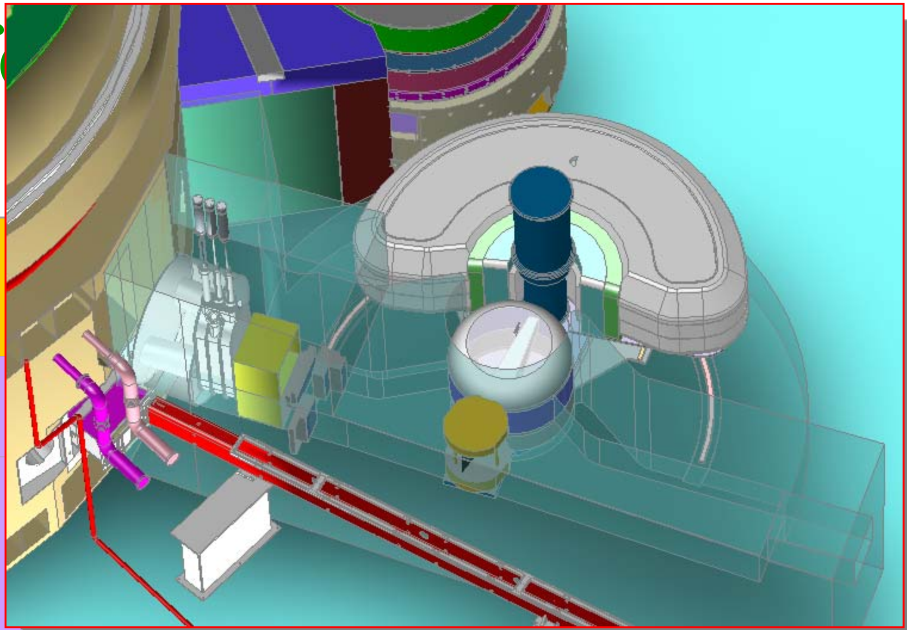
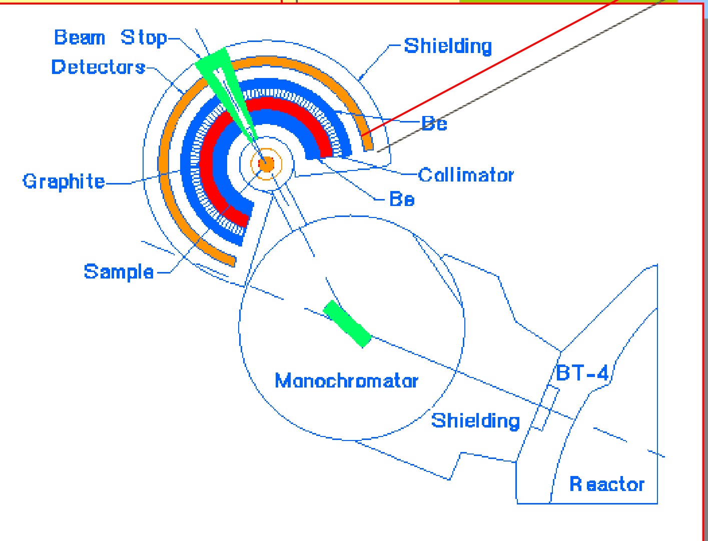
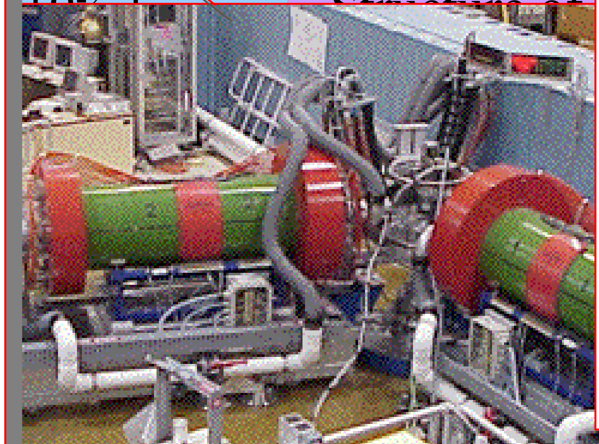
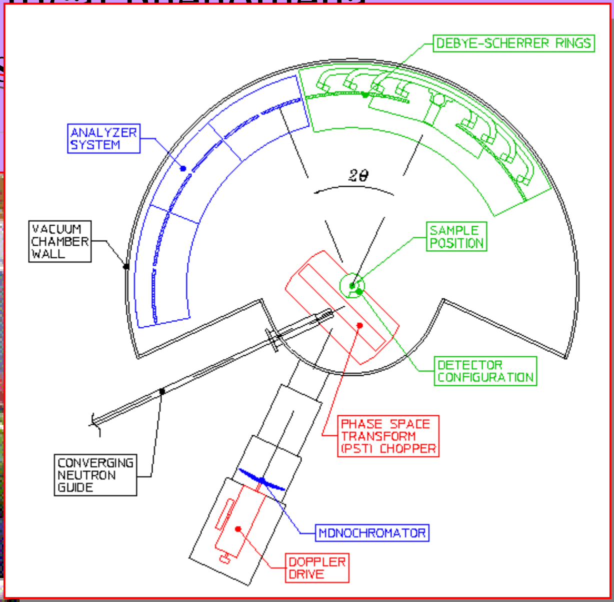


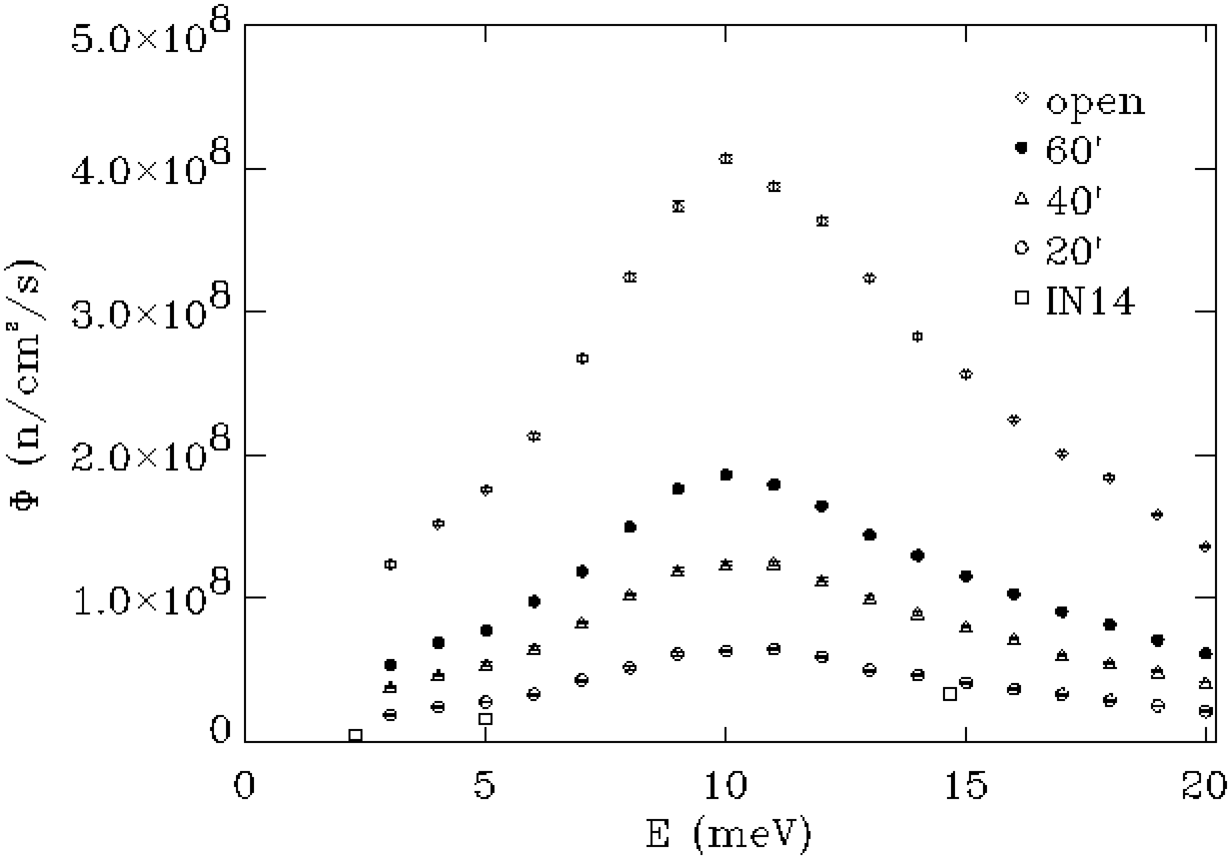
		...eV)	
Back Scattering	1999	10^{-3}	Critical Phenomena Quantum Tunelling
Disc Chopper	2001	10^{-2}-1	Quantum Critical phenomena Phonon dens...
		10^{-2}-1	Structure of...





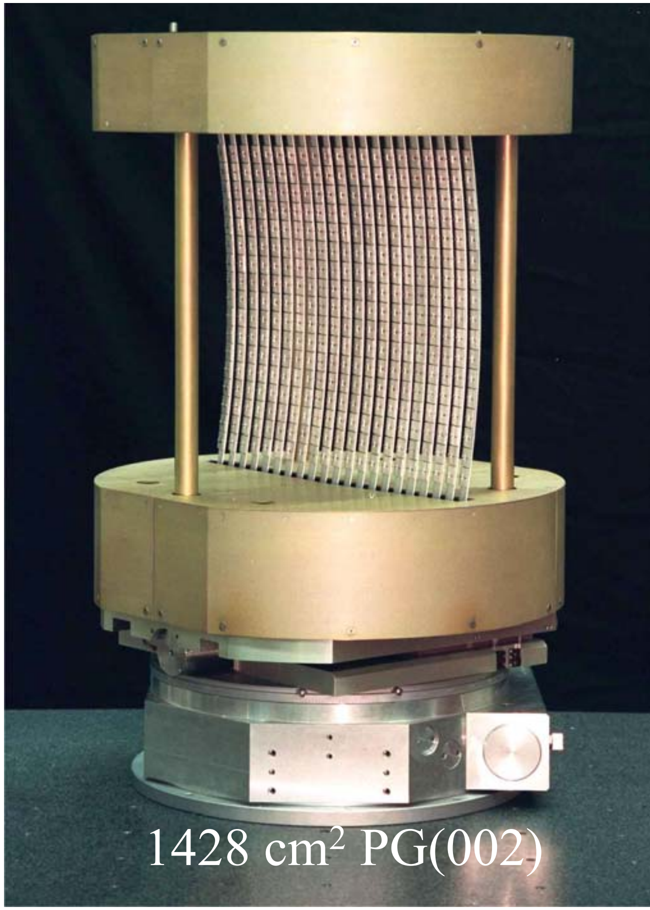


Intensity from Focusing

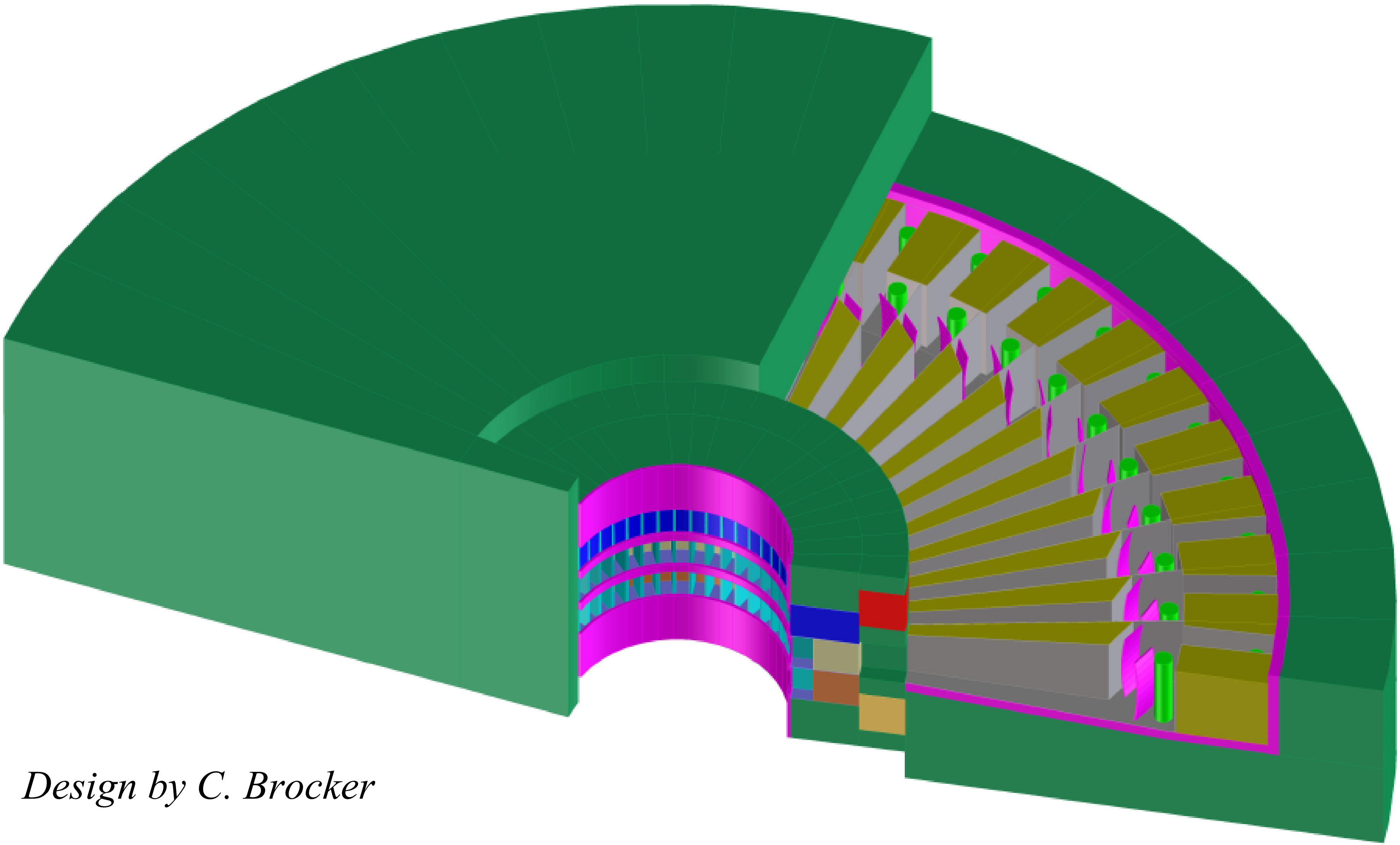


MC Simulation
Qiu and Broholm (2001)

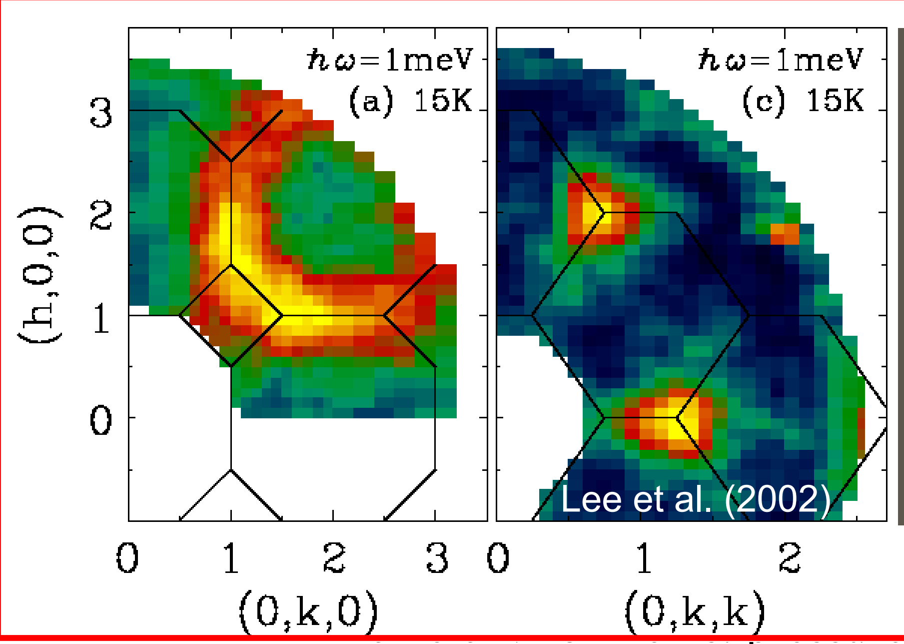
MACS monochromator



Multi-channel Monochromating Detection System



Design by C. Brocker



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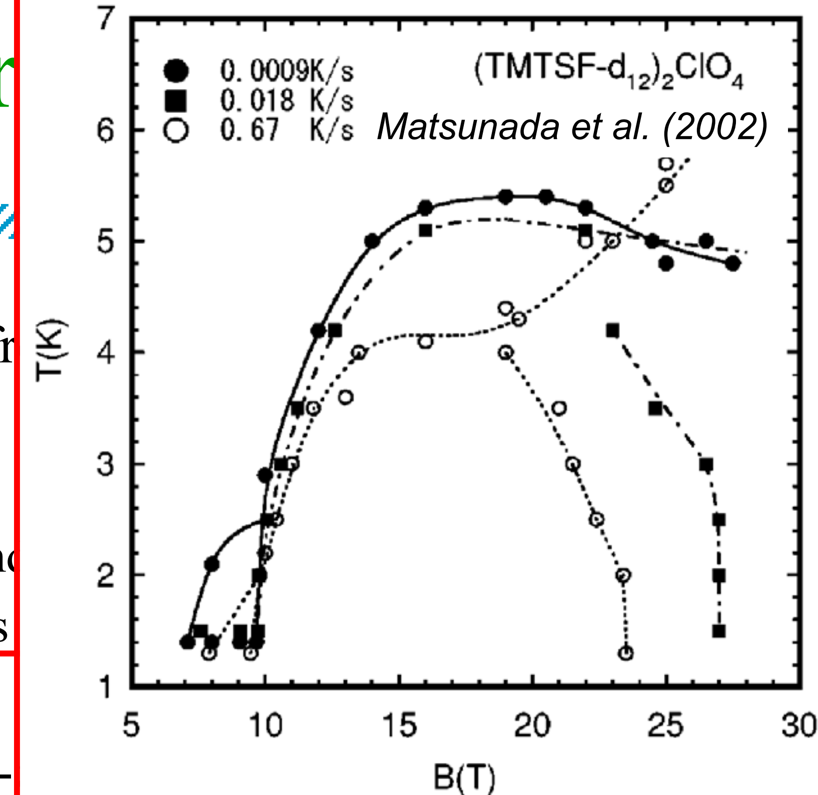
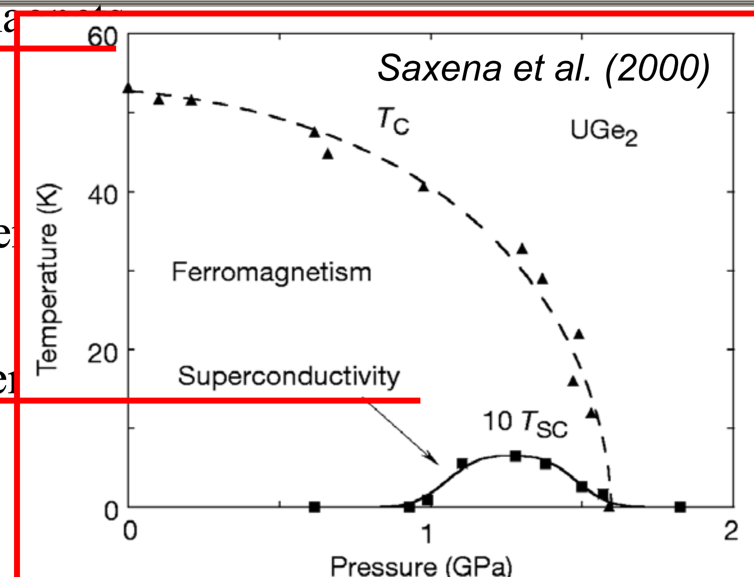
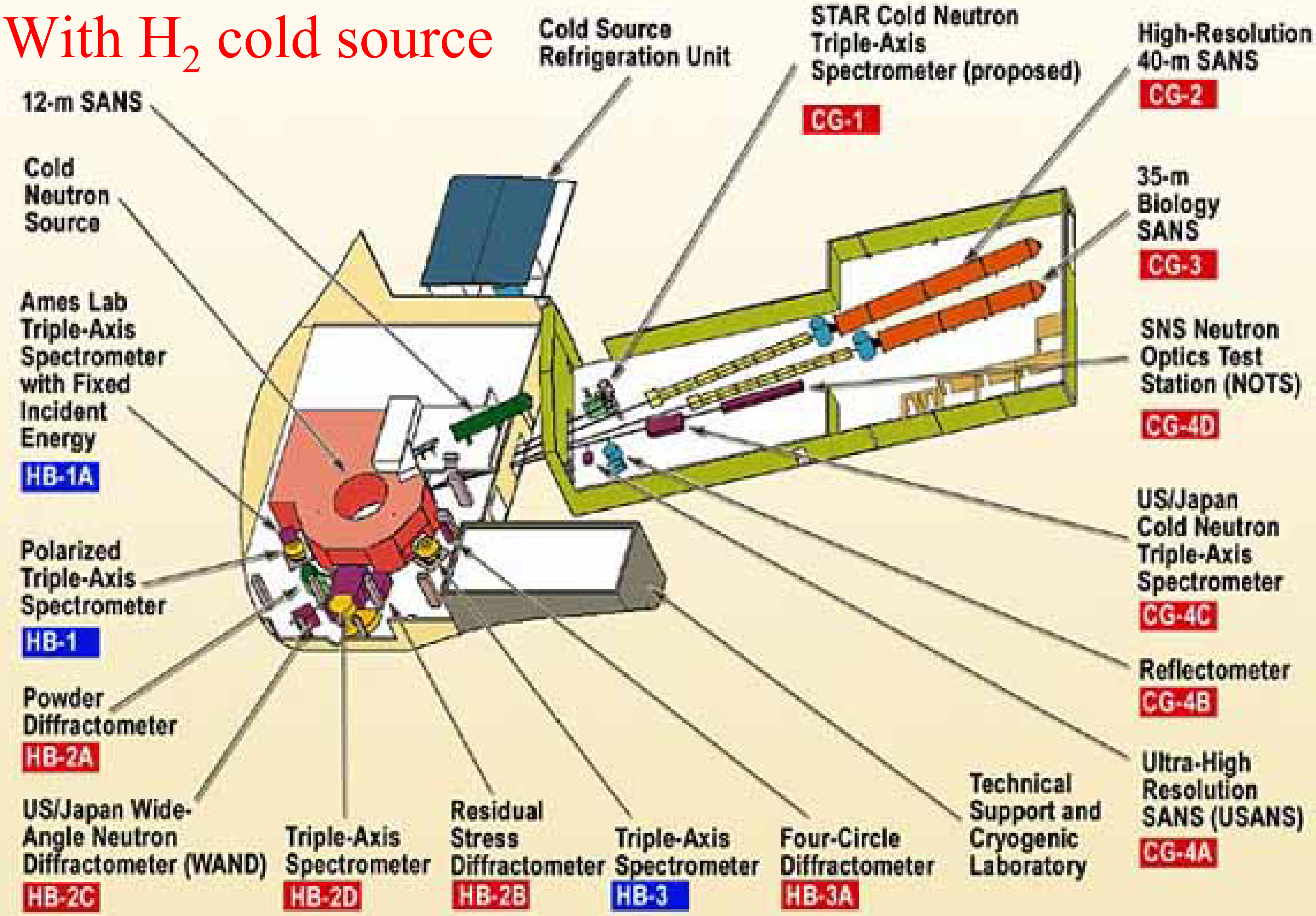


- Probing short range order
  - Solid ionic conductors, spin glasses, quasi-
    spin polarons, quantum magnets, frustrated ma
- Excitations in artificially structured solids
  - Spin waves in magnetic super-lattices
  - Magnetic fluctuations in nano-structured mate
- Weak broken symmetry phases
  - Incommensurate charge, lattice, and spin order

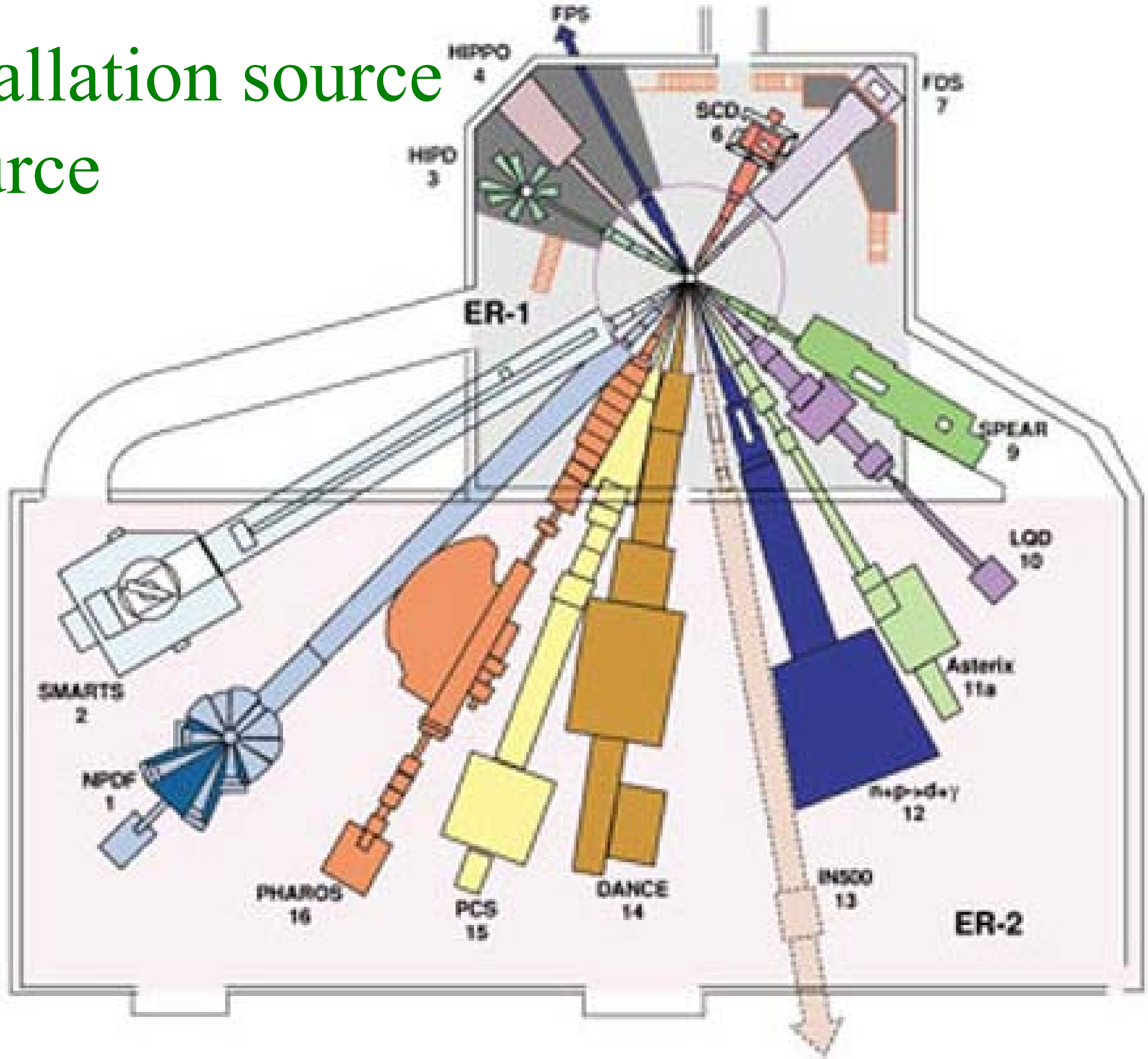


85 MW fission neutron source With H_2 cold source



Lujan Center at LANSCE

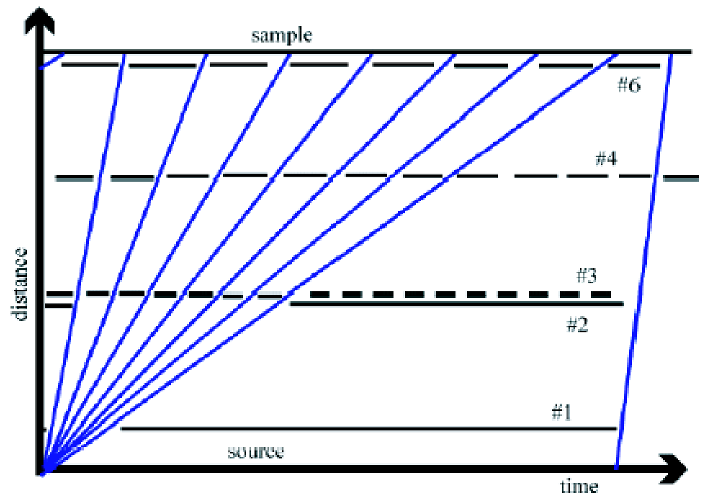
80 kW pulsed spallation source
With H_2 cold source



Upg

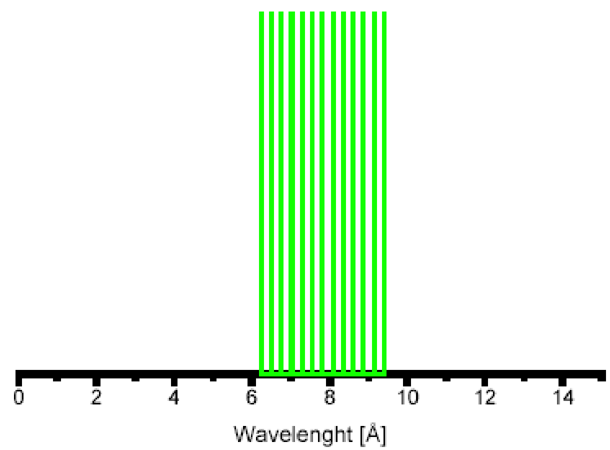
Instrume		
HIPPO I Diffracto		
SMART Diffracto		
Protein Crystallo		
PHARO Spectron		
ASTERI reflectometer		
IN500 μeV Spectrometer	2004	

- Repetition Rate Multiplication Principle
  - use of a set of monochromatic pulses from each source pulse, instead of a single one



Time-distance diagram of IN500 spectrometer

Source + all choppers
High resolution



Calculated transmission at the sample position

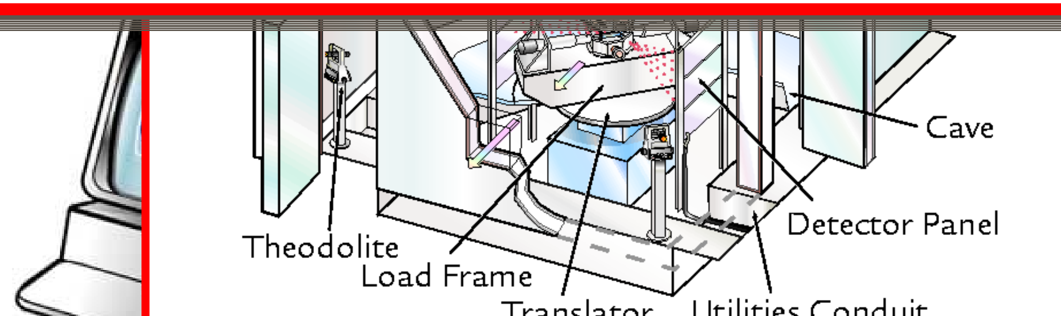


Fig. 1a

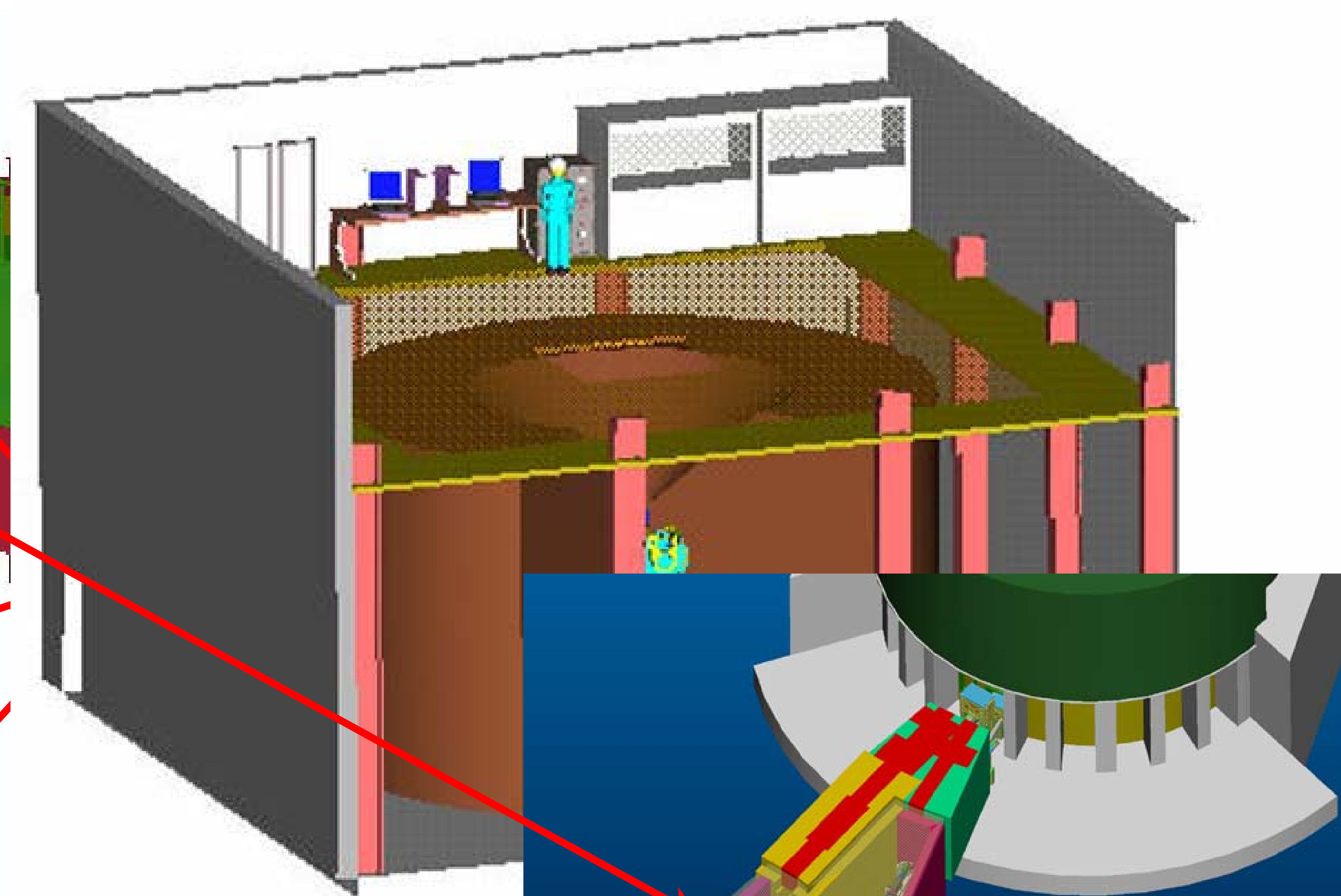
SNS October 2002

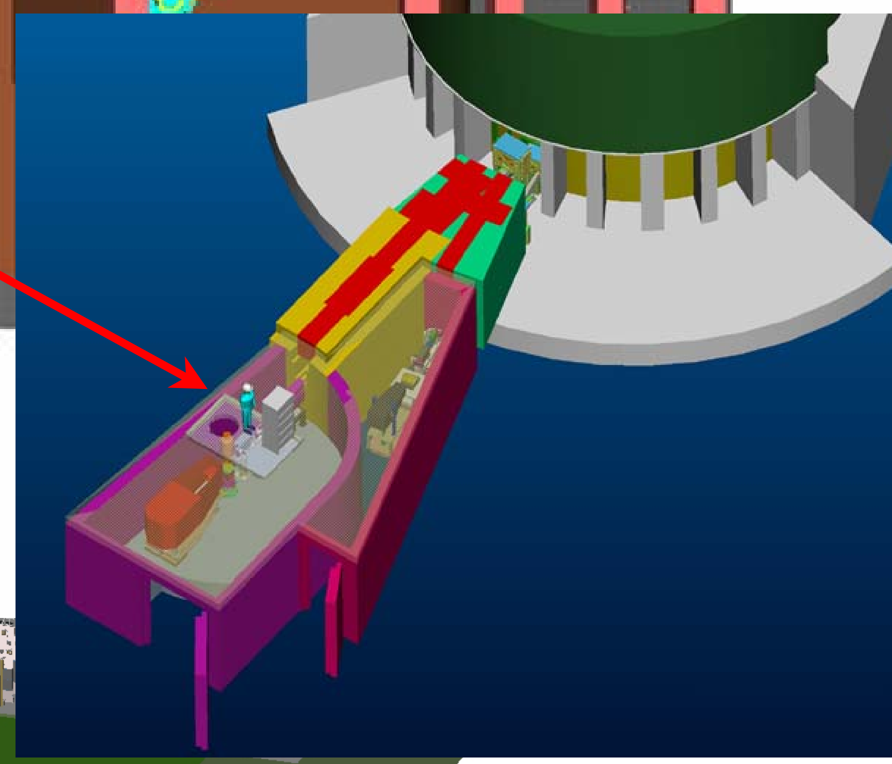
SNS beam line instrumentation

- Diffraction
  - Powder diffractometer
  - SANS with wide angle coverage
  - Disordered Materials Diffractometer
  - Single Crystal Diffractometer
  - Residual Strain mapping
- Reflectometry
  - Magnetism polarized beam
  - Liquids reflectometer
- Spectroscopy
  - Back Scattering Spectrometer
  - Cold neutron Chopper Spectrometer
  - High intensity Fermi Chopper
  - Polarized beam crystal spectrometer
- Fundamental Physics

- High Pressure Diffraction

- High Resolution Chopper
- Spin Echo spectrometer
- Chemical Spectroscopy





meV-eV Spectrometer		
μeV-meV Spectrometer	2006	3%<Δ 0 meV<Δ

Neutrons in the 21 century

- Systematic rapid access to chemical and magnetic structure with medium cell size from powder and x-tals
- Chemical and magnetic structure at the interfaces of nano-scale artificially structured systems
- Excitations in materials patterned on the nano-scale
- Protein structure (including D-positions) and dynamics
- Complete 4 D **Q**-E mapping of dynamic correlation function for spin and lattice in large single crystals $0<E<100$ meV
- Systematic access to order parameters of weak or complex broken symmetry phases
- Inelastic neutron scattering as a super-susceptometer for screening new materials
- Parametric and complete information about structure of matter under extreme conditions

Conclusions

- Neutrons are great but we don’t have enough yet
- New sources and instrumentation will open this powerful probe to a broad range of science and technology
- Now is an excellent time to get involved in neutron scattering
  - Send students to summer schools
  - Try existing facilities on your problems
  - Hire post doctoral fellows, neutron scattering faculty
  - Let SNS know what type of instrumentation
  - Get involved with instrumentation projects